UNIT D

3.0

Changes in global energy transfer could cause climate change, and impact human life and the biosphere.

Key Concepts

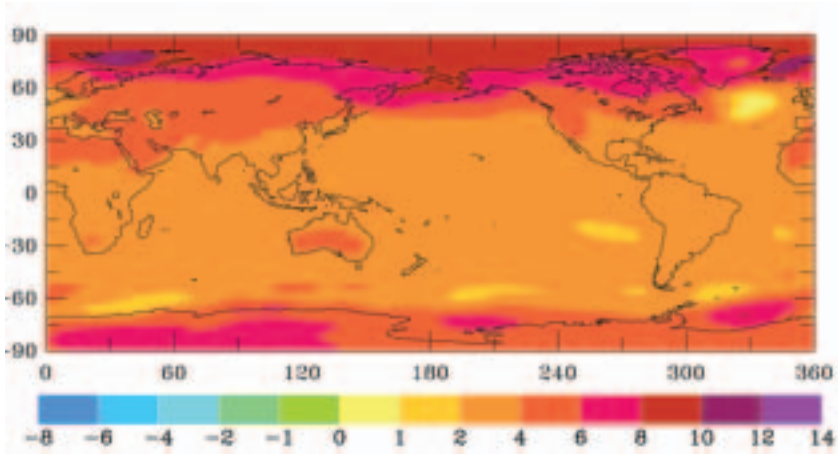
In this section, you will learn about the following key concepts:

- social and environmental contexts for investigating climate change
- human activity and climate change

Learning Outcomes

When you have completed this section, you will be able to:

- describe and explain the role of various gases—including methane, carbon dioxide, and water vapour—in determining the scope of the greenhouse effect
- investigate and identify human actions affecting biomes that have a potential to change climate and critically examine evidence that these factors play a role in climate change
- identify evidence to investigate past changes in Earth's climate
- describe and evaluate the role of science in furthering the understanding of climate and climate change through international programs
- describe the role of technology in measuring, modelling, and interpreting climate and climate change
- describe the limitations of scientific knowledge and technology in making predictions related to climate and weather
- identify the potential effects of climate change on environmentally sensitive biomes
- assess, from a variety of perspectives, the risks and benefits of human activity and its impact on the biosphere and the climate



Source: Dai et al. 2001

FIGURE D3.1 Predicted increase in global temperature that could occur from 2170 to 2199, based on expected increases in greenhouse gas levels. The image was generated by computer modelling, using data on average global temperatures and greenhouse gas levels that occurred between 1970 to 1999.

Figure D3.1 shows a computer simulation of the predicted effects of changes in the levels of greenhouse gases in our atmosphere over the next 200 years. The red areas denote warmer than average temperatures. Scientists use current climate data in climate modelling programs, such as the one that produced this simulation, to predict potential changes to our climate. However, just predicting what may happen to climate is not in itself the goal of these studies. Scientists use these predictions to assess the impact that climate change could have on all life on Earth. For example, the Government of Canada publication *Canada Country Study: Climate Impacts and Adaptation 1997* was the first assessment of the social, biological, and economic impacts of climate change to Canada. In this report, scientists suggested that climate change could cause an increase in average air temperature and a decrease in average soil moisture, events that would impact every facet of the life of Canadians. In this section, you will evaluate some of the evidence that indicates we are currently experiencing climate change. You will also investigate evidence that human activity is contributing to climate change, and consider the effects that climate change could have on human society. Some strategies for reducing the effect of human activities on climate change will also be presented.

D 3.1 Climate Change—Examining the Evidence

Is human activity affecting climate? The vast majority of climatologists agree that we are currently experiencing climate change, and that human activity has played a role. However, we do not yet understand enough about long-term climate cycles, or about the interacting factors that control climate, to accurately predict the rate of climate change or its consequences.

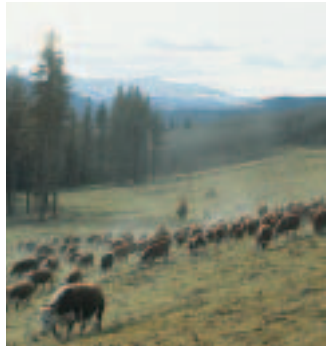


FIGURE D3.2 Modern agricultural practices are one contributor of greenhouse gases.

Changes in Greenhouse Gases

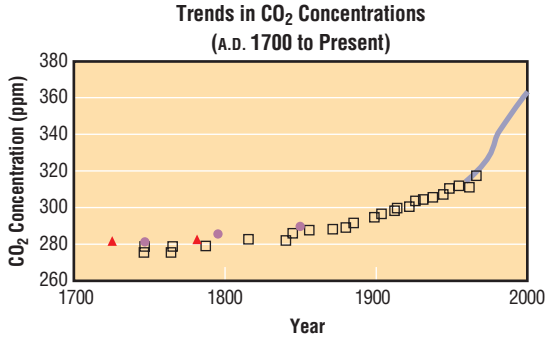
In section D2.1, you found out that the natural greenhouse effect keeps our planet warm by absorbing some of the thermal energy radiated by Earth's surface. The natural greenhouse effect is due mainly to the presence of water vapour in our atmosphere, but other greenhouse gases also play a significant role. Some of these gases are produced by human activity, such as agriculture (Figure D3.2).

TABLE D3.1 Global Warming Potential of Three Main Greenhouse Gases

Gas	Global Warming Potential	Persistence (y)
carbon dioxide	1	50–200
methane	23	10
nitrous oxide (N_2O)	296	120

There are four main greenhouse gases: water vapour, carbon dioxide, methane, and nitrous oxide (N_2O). Table D3.1 gives the Global Warming Potential (GWP) of three of these gases. GWP is a measure of the ability of a gas to trap thermal energy in the atmosphere. Since carbon dioxide is the most common greenhouse gas, it is given a rating of 1. All other greenhouse gases are then rated relative to carbon dioxide. The persistence (time the gas remains in the atmosphere) is also given. Gases that persist longer will absorb thermal energy over a longer time period.

Analysis of ice core samples from Greenland and Antarctica, and of atmospheric data collected from the last few decades, has led scientists to conclude that the atmospheric concentrations of carbon dioxide (Figure D3.3), nitrous oxide (N_2O) (Figure D3.4), and methane (Figure D3.5) have increased over the time period of about A.D. 1700 to A.D. 2000.



Source: Environment Canada

FIGURE D3.3 This graph shows the changes in worldwide atmospheric carbon dioxide (CO_2) levels over time, from about 1700 to 2000. Data were collected either by analyzing ice core samples from three sites in polar regions (triangles, squares, and circles) or directly measured in atmospheric gases (line).

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Every tonne of carbon burned releases 3.7 tonnes of carbon dioxide gas into the atmosphere.

Since greenhouse gases absorb heat, changes in the levels of these gases could change the net radiation budget of Earth. Increased greenhouse gas levels could mean that less thermal energy is released back into space, and the average temperature at Earth's surface could increase as a result.

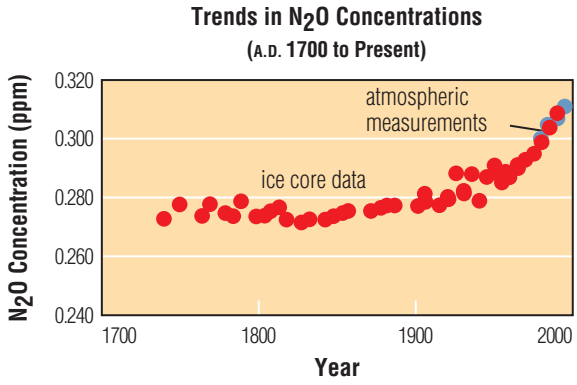

FIGURE D3.4 This graph shows the changes in worldwide atmospheric levels of nitrous oxide (N_2O) over time, from about 1700 to 2000. Data were collected from ice core samples only for the earlier dates (up to about 1900). Data from about 1900 to 2000 include measurements from ice core samples and directly from samples of atmospheric gases.

Source: Environment Canada

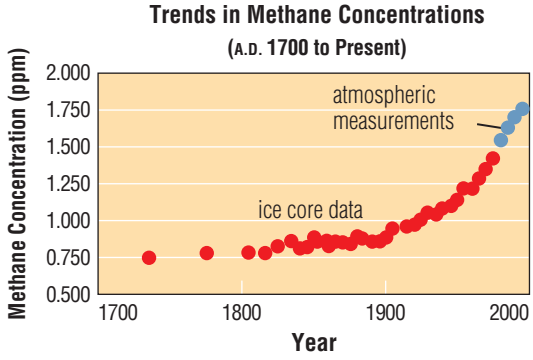

FIGURE D3.5 This graph shows the changes in worldwide methane (CH_4) levels in the atmosphere from about 1700 to 2000. Measurements were obtained either through analysis of ice core samples, or by direct determinations from atmospheric gas samples.

Source: Environment Canada

Skill Practice — Extrapolating Data

To predict the results of the increase in greenhouse gases, scientists extrapolate existing data into the future. **Extrapolation** is the process of estimating the value of a measurement beyond the known or measured values of a set of data. For example, you might estimate how tall you will be next year based on your rate of growth over the last 5 years.

How reliable is extrapolated data? Using the graphs in Figures D3.3, D3.4, and D3.5, respond to the following:

1. How does the change in carbon dioxide gas concentrations over time compare to changes in the other two greenhouse gases?
2. By how much has the concentration of each gas increased since 1750?
3. Express the increase in the concentration of each greenhouse gas as a percent change.
4. Extrapolate to predict the concentration of each greenhouse gas in 100 years.
5. What assumptions did you make when you extrapolated the data on greenhouse gas concentrations?
6. Are you more confident about the accuracy of the answer to question 2 or to question 4? Why?

Greenhouse Gases and Human Activity

The increase in the levels of greenhouse gases since the start of the Industrial Revolution in the late 18th century is a direct result of changes in human activity (Figure D3.6). During this time, human society became more and more dependent on fuel consumption, especially fossil fuels. **Fossil fuels** are fuels that contain large amounts of carbon, that were formed from the remains of living organisms. Coal, oil, and natural gas are the most commonly used fossil fuels. Producing fossil fuels releases methane and carbon dioxide gases into the atmosphere, while burning fossil fuels releases carbon dioxide and nitrous oxide (formed when atmospheric N_2 and O_2 combine during combustion). The most significant increase in concentration of gases from fossil fuel combustion has been in carbon dioxide. Any process that releases carbon dioxide to the atmosphere is called a **carbon source**. Burning fossil fuels is a carbon source, since it releases carbon dioxide to the atmosphere. The respiration of living things is also a carbon source, since this process releases carbon dioxide to the atmosphere.

FIGURE D3.6 The Industrial Revolution increased the emission of carbon dioxide at a rate never before seen.

At the same time, people were migrating into wilderness areas and clearing land of forest to provide timber for fuel and construction and to prepare areas for agriculture. Forests play an important role in removing carbon dioxide from the air, through the process of photosynthesis. Photosynthesis is a **carbon sink**, which is any process that removes carbon dioxide from the atmosphere. Large amounts of atmospheric carbon dioxide dissolve in Earth's oceans and lakes and are removed from the atmosphere. This process is also an important carbon sink. The loss of forest cover during the last two centuries reduced the size of Earth's carbon sinks, and therefore decreased the amount of carbon dioxide being removed from the atmosphere. Loss of forest cover continues today worldwide.

When the release of carbon dioxide to the atmosphere by carbon sources is equal to the amount of carbon dioxide removed from the atmosphere by carbon sinks, the amount of this greenhouse gas remains stable (Figure D3.7). However, the balance between carbon sinks and carbon sources has shifted since the Industrial Revolution, causing the levels of carbon dioxide in our atmosphere to increase. According to scientists at the Carbon Dioxide Information Analysis Center in the United States, the concentration of carbon dioxide gas in the atmosphere has increased by 32% over the last 200 years.

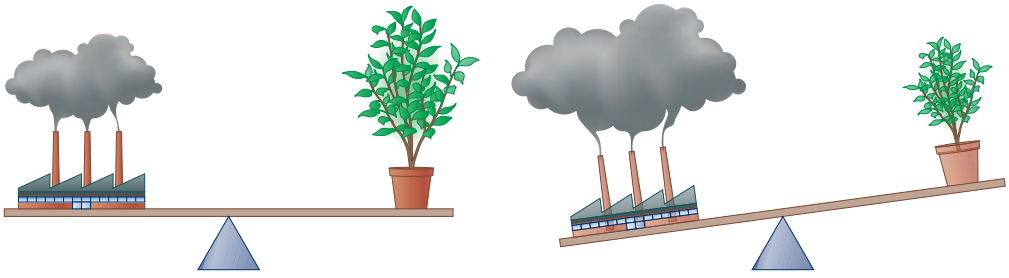

FIGURE D3.7 (a) When the action of carbon sources is equal to the action of carbon sinks, atmospheric levels of carbon dioxide remain stable.

(b) Over the 20th century, the number of carbon sources increased and the number of carbon sinks decreased, causing atmospheric carbon dioxide levels to increase.

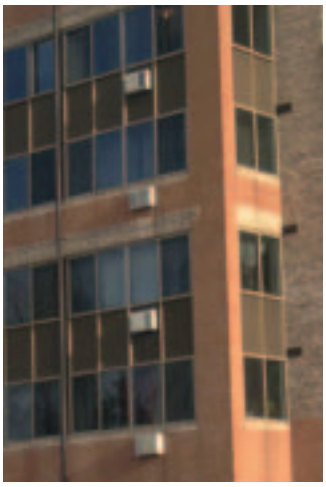

FIGURE D3.8 Halocarbons are human-made chemicals that have many useful applications, such as in air conditioners, where they act as coolants. When halocarbons are released into the atmosphere, they are powerful greenhouse gases.

Agriculture is another human activity that contributes greenhouse gases to the atmosphere. Nitrous oxide is released by the use of manure and chemical fertilizers, a worldwide practice. Methane is emitted from rice paddies and from the digestive systems of cattle and other animals. Other human practices also contribute greenhouse gases to the atmosphere. For example, decaying garbage in landfill sites releases methane, as does decaying vegetation in flooded areas created by dams.

Humans have also contributed greenhouse gases to our atmosphere that have never before occurred. **Halocarbons** are human-made chemicals that can absorb significant amounts of thermal energy. They are used mainly as coolants, and may be found in refrigerators and air conditioners (Figure D3.8). The ability of this group of chemicals to absorb thermal energy also makes them powerful greenhouse gases. For example, the class of halocarbons called chlorofluorocarbons (CFCs) have a Global Warming Potential of 12 000. CFCs were once commonly used in aerosols (spray bottles), air conditioners, and fire extinguishers. CFCs also undergo chemical reactions that destroy the ozone in the stratosphere, so their use is now restricted.

Greenhouse Gases and Climate Change

Most scientists have concluded that the increased emission of greenhouse gases by human activity has influenced global climate. The **enhanced greenhouse effect** is the change in Earth's net radiation budget caused by the increase in human-generated greenhouse gases. Temperature data collected from around the world show that the global average temperature increased by 0.6°C, during the period from 1880 to 1999 (Figure D3.9). This time span was also the period when changes in human activity, such as those of the Industrial Revolution, increased the amount of greenhouse gases emitted to the atmosphere.

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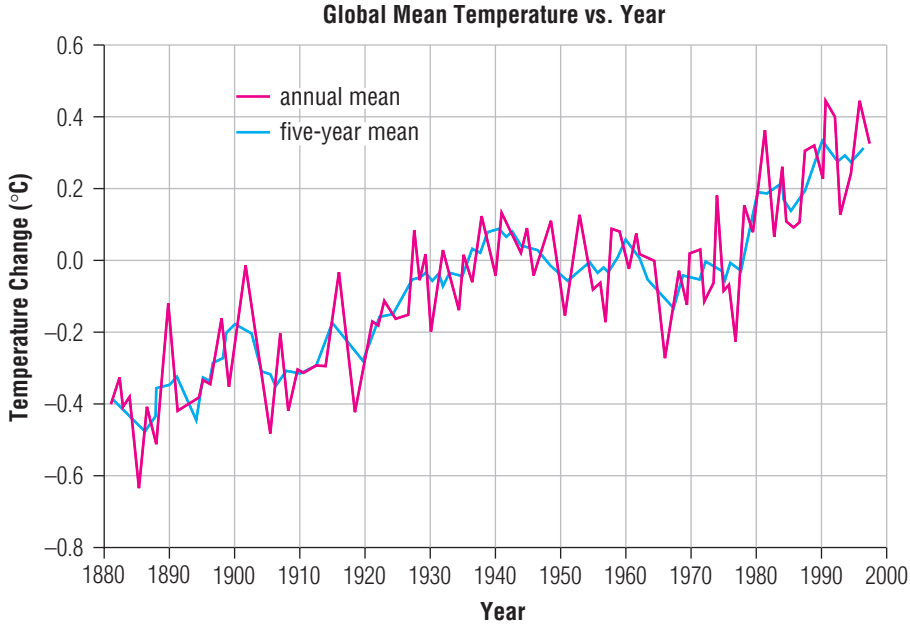
In 2001, Canada contributed about 1.8% of the world's greenhouse gas emissions from human activities, which was the second-highest in the world, on a per person basis.



Source: Environment Canada

FIGURE D3.9 Change in the global average surface temperature since 1880 as compared with the average temperature from 1951 to 1980. The zero point on the vertical scale indicates no change from the 1951 to 1980 average surface temperature. Positive values indicate a year in which the average temperature was above the 1951 to 1980 average; negative values indicate years in which the average temperature was below the 1951 to 1980 average.

Global warming refers to the observed increase in Earth's average temperature. Global warming has been detected in all regions of Earth, by global organizations that collect and share information related to climate change. One of the most important of these organizations is the Intergovernmental Panel on Climate Change (IPCC), an international group of scientists brought together by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to assess information related to climate change. The IPCC has linked global warming to the increase in the amount of greenhouse gases in the atmosphere. The majority of scientists think that if we continue to produce high levels of greenhouse gases and decrease the number of carbon sinks, global warming will continue and eventually result in climate change.

FIGURE D3.10 Severe storms may be one result of climate change.

Global warming is one piece of evidence that Earth is currently undergoing climate change. Other observed changes suggest that climate change may be affecting biomes. Using satellite data and historical records from 1936 to 1998, scientists from the University of Alberta and the Institute of Ocean Sciences have found that, over the past century, flowers in the Northern Hemisphere have begun to bloom an average of 26 days earlier, due to a change in the date that spring-like conditions begin. Many regions on Earth, including Canada, have experienced severe weather-related disasters in the recent past (Figure D3.10), such as the flooding of Manitoba's Red River in 1997 and the crippling ice storm that hit Ontario and Quebec in 1998. Changes in the frequency and severity of storms are one potential effect of a rapid increase in average global temperature. In some areas of Earth, such as in the Canadian Arctic, the amount of snow cover and ice has decreased. The average level of the world's oceans has increased by 2 to 5 cm over the past century, which is most likely related to the decrease in ice cover. Some areas of the world's oceans have also increased in temperature, which may be related to the decline in stocks of fish such as Pacific salmon and Atlantic cod.

Evaluating the Evidence of Climate Change

The IPCC publishes their findings in comprehensive reports that are available to governments, industry, citizens groups, scientists, and the general public. Information from international groups like the IPCC can help us to make more informed decisions related to climate change.

Although most scientists agree we are experiencing global warming, the potential effects on the biosphere are not clear. The study of climate is still a very challenging field. Scientists do not yet fully understand all the interactions between the lithosphere, hydrosphere, and atmosphere in transferring thermal energy. Even seemingly simple factors, such as the effect of cloud cover on the net radiation budget, have turned out to be very complex. As a result, there are limits on the accuracy by which scientists can evaluate the evidence for climate change, and the effect of human activity on climate.

TABLE D3.2 IPCC Confidence Ratings

Confidence Rating	Probability That Result Is True
virtually certain	> 99%
very likely	90–99%
likely	66–90%
medium likelihood	33–66%
unlikely	10–33%
very unlikely	1–10%
exceptionally unlikely	< 1%

Scientists have therefore found ways of estimating their confidence in evaluations and predictions. Through statistical and other means, all analyses of data can be given a particular level of confidence. The IPCC uses the rating scale, shown in Table D3.2, to communicate the level of confidence that can be attributed to events related to climate change. Some of those events are shown in Figure D3.11. Analyses and predictions are given a higher confidence level when there are more data (such as long-term temperature measurements), more accurate measurements (such as temperature measurements of atmospheric temperatures at various altitudes), or if scientists have a greater understanding of the factors involved in a particular climatic event (such as the effect of the time of year on insolation).

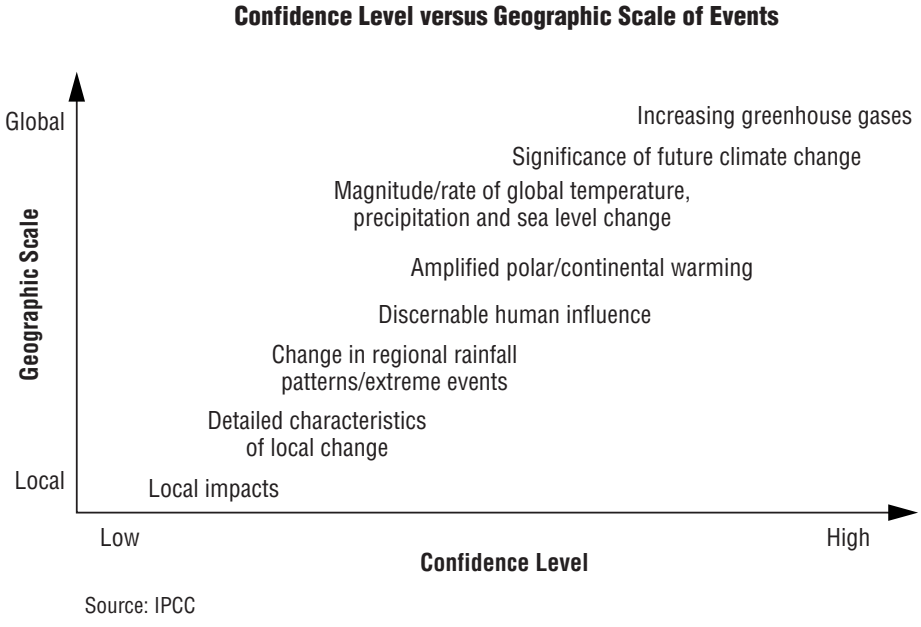


FIGURE D3.11 This graph shows events thought to be related to climate change, arranged according to IPCC levels of confidence (horizontal axis) and whether events are more local or more global in scale (vertical axis). Global events are events that are observed worldwide; local events are events that are observed only in particular regions of Earth. In general, events on a global scale can be linked to climate change with more confidence than can local events.

Activity D18

Decision-Making Investigation

Student Reference 9

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Evaluating the Potential Effects of Climate Change

Begin your search at www.pearsoned.ca/school/science10

The Issue

Although not all people agree that climate change is occurring, they do agree that climate change would affect our lives in many ways. What are the potential effects of climate change to the environment, economy, and society of Alberta?

Background Information

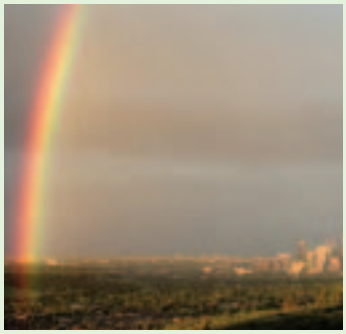


FIGURE D3.12 What effects would climate change have on Alberta?

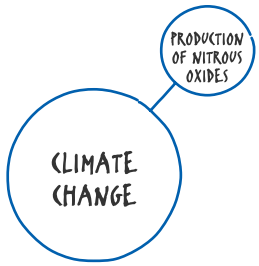
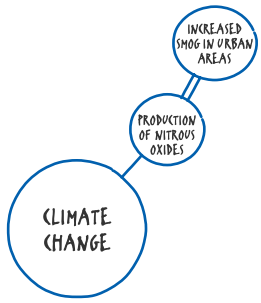
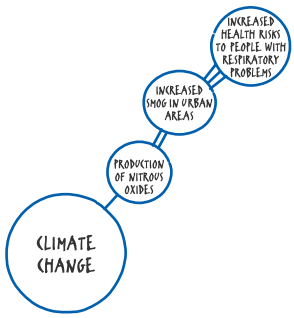
Some of the possible impacts of climate change on life in Alberta are obvious and may even appear pleasant (Figure D3.12); for example, warmer winters and less precipitation. However, climate affects every living thing in a biome, so climate change would have negative consequences in areas you might not think about right away. Using the evidence presented in this section and from your own research, you will identify some of the possible impacts of climate change to Alberta.

To help you analyze the impact of climate change, you will use a graphic organizer called an Impact Wheel. An Impact Wheel can be created on a piece of chart paper, in your notebook, or on the chalkboard in your classroom. Follow the directions in the chart to the right.

Analyze and Evaluate

1. Review your Impact Wheel. Describe any patterns you observe in your work.
2. State the impact of climate change in Alberta that was most surprising to you.

Creating an Impact Wheel

Directions	Example
An Impact Wheel starts with an issue at the centre of the wheel. The issue in this activity is climate change.	
Around the centre of the wheel, list the evidence for climate change. Circle each piece of evidence. Make a line between each piece of evidence and the centre of the wheel, so that each piece of evidence is part of a spoke on the wheel.	
For each of the pieces of evidence on your chart, list one or more possible effects of that change. Join the possible effects to the piece of evidence with a double line.	
Finally, list the possible impacts on your community or province. Join each of these points with a triple line.	

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Hydroxyl and nitrate molecules are sometimes called nature's atmospheric detergents. Find out how they help to clean the atmosphere, and how this may affect global warming. Begin your search at

www.pearsoned.ca/school/science10

Other Views on Climate Change

Scientists agree the Earth's average temperature has increased over the last century. There remains some disagreement about how much human activity contributed to this global warming, whether global warming will lead to climate change, and the consequences climate change could bring. Evidence from sources such as fossil records and ice cores suggests that Earth's climate has undergone change in the past, well before humans existed. Some scientists argue global warming today could be part of a natural climate cycle that occurs over thousands of years. Until such cycles are fully described, the human contribution to global warming will remain debatable to some people. Predicting the consequences of climate change is also difficult, because our knowledge of the factors that affect climate is limited. Climate change is a relatively new field, so there are not yet enough data to predict how quickly climate change may occur.

D3.1 Check and Reflect

Knowledge

1. What is Global Warming Potential (GWP)?
2. Identify three greenhouse gases that are generated by human activity. Describe how the atmospheric concentrations of these gases have changed over the last 200 years.
3. Describe one method that scientists use to measure changes in the concentration of greenhouse gases over time.
4. State the sources of human-generated nitrous oxide emissions.
5. Define carbon sink and give two examples.
6. What is the enhanced greenhouse effect?
7. Describe three pieces of evidence of climate change during the 20th century.

Applications

8. To assess the work of a scientist or group of scientists, the IPCC sends the work to other scientists to review and evaluate. Explain why this process increases the confidence of the IPCC in work submitted to them for assessment.
9. Explain the difference between natural and human-generated greenhouse gases.
10. Outline the reasons why emission of greenhouse gases increased after the Industrial Revolution.
11. Explain the link between photosynthesis and greenhouse gas levels in the atmosphere.
12. Create a diagram that compares the natural greenhouse effect with the enhanced greenhouse effect.
13. Some scientists and organizations disagree with the evidence presented by the IPCC on climate change. Does this mean that someone is right and someone else is wrong? Explain.

Extensions

14. List as many human activities as you can that take place in your local region that decrease carbon sinks. Make a second list of human activities in your local area that increase carbon sources. Based on your list, do you think that the balance between carbon sinks and carbon sources will change over the next 20 years? Why?
15. Do you think that climate change is occurring? Write a persuasive paragraph outlining and defending your viewpoint.

D 3.2 International Collaboration on Climate Change

Since climate change could have many consequences, the world's scientists, governments, and citizens have agreed to act now on human actions that contribute to climate change (Figure D3.13). As you have seen in the previous sections of this unit, the problem of climate change is complex and not yet fully understood, so it is a challenge just to decide what to do first. Because climate change is a global issue, the political, environmental, and social issues involved can sometimes make action difficult.

FIGURE D3.13 Climate change is a global issue that requires international co-operation and personal action.

Scientific Collaboration on Climate Change

As scientists gather more data and learn more about climate, the confidence level of their predictions increases. Climate research depends on international co-operation. In order to do the best possible job, scientists must share climate data and access to the tools to collect and analyze the data. A recent IPCC report on climate change (Figure D3.14) stated that "confidence in the ability of models to project future climate has increased." This is in large part due to the willingness of the world's scientists to work together.

Advances in technology have also contributed to the increased confidence level. For example, scientists have achieved a better understanding of how water vapour and other greenhouse gases affect global climate. Better computers and software have given us computer simulations and models that can analyze and more accurately predict the effects of human activities, such as the emission of more carbon dioxide into the atmosphere.

There are a number of different types of computer models of climate, but the one that reflects the observed climate data of most climates is the **general circulation model (GCM)**. These highly sophisticated models incorporate the laws of physics to model climate on a global scale. GCMs centre on the effects of changes that affect Earth's energy balance (e.g., changes in insolation, albedo, and/or absorption) on thermal energy transfer in the atmosphere. Since climate modelling is very expensive, scientists must often pool their resources to use this technology to the best advantage.

Since GCMs reflect the world's climate the best, it may seem that all climate modelling should be done using this type of model. When choosing which model to use, scientists consider the problem they are investigating, and the type of data that are available. In some cases, other models will produce a result with a higher level of confidence than will GCMs.

Predictions made by a climate model can be only as good as the data on which the model is based. Satellites, high-altitude jets, and deep-sea submarines now collect data from previously unreachable areas of our planet. The type and quantities of gases and dust in Earth's atmosphere can be measured more accurately because of improvements in scientific instruments. Nations must also share this data in order to get an accurate picture of climatic events.

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As of May 11, 2001, there were 2671 satellites orbiting Earth, of which 17 were owned by Canada. These satellites serve many functions, from monitoring Earth's surface and climate to relaying cellular communications signals.

FIGURE D3.14 The IPCC reports that confidence in computer models is increasing, which is in part due to international collaborations between scientists.

Dr. Andrew Weaver is a world-renowned climate research expert.

Andrew Weaver

Dr. Andrew Weaver is widely known as one of Canada's leading experts on climate change. Dr. Weaver is currently a faculty member at the University of Victoria in British Columbia, where he is developing climate change models of the changes in Earth's climate over the past 400 000 years.

How do you determine what Earth's climate was like 400 000 years ago?
My research group and I have developed the UVic Earth System Climate Model, which contains interactive sea ice, glaciological, ocean, atmosphere, and land surface components. This model will help us to understand the feedbacks between land and ocean surface properties and climate that occurred over the last 400 000 years. We compare modelling results with actual climate data for this same period.

Why did you choose to study climate change?
When I first started, I was studying the role of the ocean in climate. I thought then that the ocean played such an important role that the effect of changes in greenhouse gas levels would be dwarfed by the natural variability of the ocean atmosphere system. In trying to prove this, I proved instead that I was wrong! When I started understanding the problem, I realized that climate change is perhaps the greatest issue facing humanity this century. I am now involved with international committees, such as the IPCC, that are concerned with climate change.

Why should the average Canadian care about the IPCC reports on climate change?
The IPCC provides a comprehensive assessment of our understanding of the science behind climate change. The IPCC reports are extremely influential in providing the scientific foundation on which governmental policy is based.

1. What do you think would be the most challenging part of Dr. Weaver's job?
2. In the future, do you think there will be a greater or lesser need for research scientists like Dr. Weaver in the area of climate change? Why?
3. Why do climate-change scientists often study all fields of science, instead of just one?

Political Collaboration on Climate Change

As our understanding of global energy systems improves, the challenge becomes one of ensuring international co-operation to reduce the contribution of human activity to global warming. The government of Canada has entered into several agreements with other nations to make changes that will benefit the atmosphere and alter Canada's contribution to climate change.

The Montreal Protocol

The **Montreal Protocol** is an international agreement to phase out the production and use of CFCs, and was the first international agreement concerning Earth's atmosphere. It was signed in 1987 by 182 nations, including Canada. CFCs were invented in 1946, to replace many flammable and toxic compounds formerly used by industry. CFCs were used in many products, including aerosol cans, fire extinguishers, and air conditioners. In the 1970s, the chemists Mario Molina and F. Sherwood Rowland showed that CFCs react with the ozone in the atmosphere, converting it to oxygen. Even a very small amount of CFCs can cause a significant loss of ozone. CFC emissions are thought to be the main cause of the thinning of the ozone layer that has been observed over Antarctica (Figure D3.15) and other regions.

Ozone absorbs much of the ultraviolet radiation from the Sun's rays, so loss of ozone results in more ultraviolet radiation reaching the surface of Earth. This could change the net radiation budget of areas of Earth, and cause an increase in the global average temperature. Thinning of the ozone layer could also cause an increase in the rates of cancers caused by exposure to ultraviolet radiation, such as skin cancer.

Hydrochlorofluorocarbons, or **HCFCs**, are chemicals with similar properties to CFCs, but which destroy ozone much more slowly. The Montreal Protocol specifies that nations ban use of CFCs and replace them with HCFCs over a specified time span. HCFCs are still only a temporary solution to the problem of ozone depletion. Scientists are working to find other chemicals to replace HCFCs that do not harm the environment. The Canadian government plans to ban HCFCs by 2020.

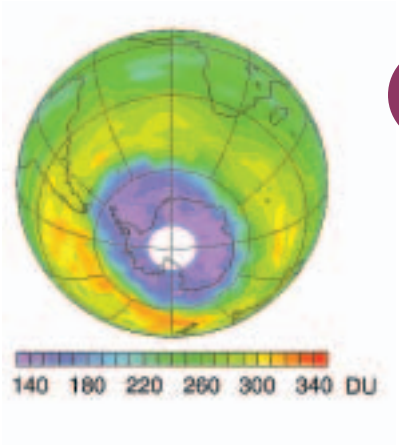


FIGURE D3.15 This computer simulation shows the thickness of the ozone layer over Antarctica on August 30, 1996. Areas in purple are the thinnest. Ozone levels are given in Dobson units (DU): 1 DU is equal to 2.69×10^{16} molecules per cm^2.

United Nations Framework Convention on Climate Change

The **United Nations Framework Convention on Climate Change** (UNFCCC) is an agreement by the world's nations to act to stabilize greenhouse gas emissions caused by human activity (Figure D3.16). The UNFCCC is not an action plan like the Montreal Protocol. Instead, it sets out a process for making international agreements on future actions related to climate change. The UNFCCC marked the first time the world community acknowledged that human activities could cause climate change.

The nations that signed the UNFCCC also agreed that any actions taken to stabilize greenhouse gas emissions must not threaten global food production or the economic interests of any nation, and must support sustainable development. **Sustainable development** is the use of the world's resources in ways that maintain these resources for future generations with minimal environmental impact. For example, to meet the standards of the UNFCCC, the forestry industry in Canada must harvest our forests in a manner that ensures

FIGURE D3.16 The United Nations Framework Convention on Climate Change was the first agreement by the world's nations to act on a global problem before having absolute proof that the problem would occur.

that the total amount of forest cover does not decrease. Photosynthesis by forest plants is a carbon sink that removes large quantities of carbon dioxide from the atmosphere, which plays an important role in stabilizing greenhouse gases. Forests also provide habitat for many wildlife species, recreational opportunities for humans, and contribute to the hydrologic cycle. These roles, along with the economic importance of forestry, must be considered whenever Canada proposes any change to its forestry practices.

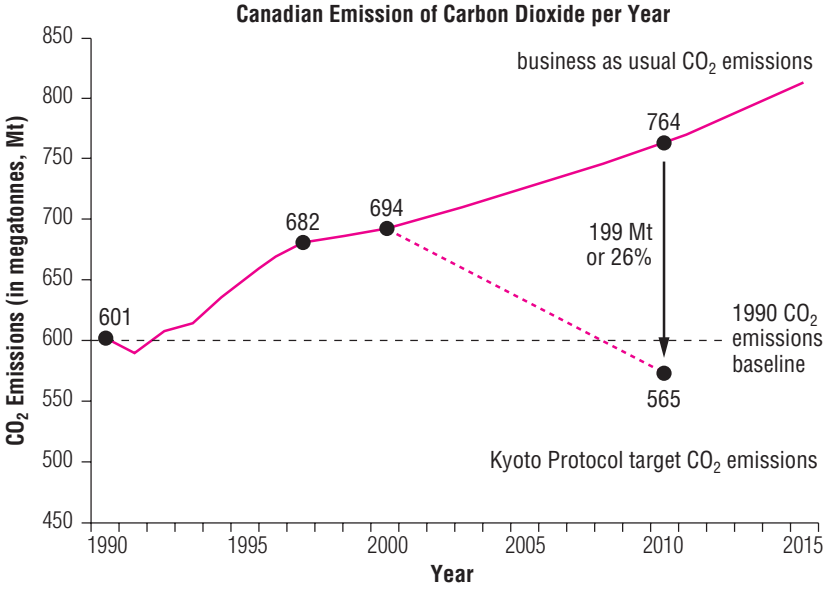
Kyoto Protocol on Climate Change

The UNFCCC provided the foundation for the **Kyoto Protocol**, an international agreement to reduce the production of greenhouse gases. In 1998, Canada and 160 other countries agreed in principle to set a goal of a 5% reduction in global greenhouse gas emissions by 2012. According to the Kyoto Protocol, Canada must reduce its emissions of greenhouse gases to 6% below 1990 levels. Figure D3.17 shows Canada's past and predicted greenhouse gas emissions, with and without the changes proposed by the Kyoto Protocol.

A key feature of the Kyoto Protocol is a concept called emission-reduction credits. **Emission-reduction credits (ERCs)** are credits given to a country for actions that contribute to the global reduction of greenhouse gas emissions. ERCs are not a reduction in the emissions of that country. ERCs are awarded for the following actions:

- when a developed country helps a developing country to reduce its emissions;
- when a developed country helps another developed country that has a temporary economic problem to reduce its emissions: for example, developed countries recovering from a major war or natural disaster might qualify;
- when a country engages in practices that help to remove carbon dioxide from the atmosphere, such as planting trees to reforest a logged area.

The emission-reduction credit system allows some flexibility in how nations meet their goals, and so allows them to more easily make sustainable changes. However, some people see the ERCs as a way for richer nations to avoid having to reduce the amount of greenhouse gases they emit.



Source: Environment Canada

FIGURE D3.17 Since the Industrial Revolution, economic growth was always associated with an increase in greenhouse gas emissions. By meeting the commitments of the Kyoto Protocol, Canada could produce about 25% fewer carbon dioxide emissions in 2012 than would be expected from normal economic growth (business as usual).

Activity D19

Decision-Making Investigation

Student Reference 4

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

Future Options

Begin your search at
www.pearsoned.ca/school/science10

The Issue

How are international collaborations and decisions related to climate change important for your future?

Background Information

Throughout this unit, you have been investigating the science of global energy systems and the potential of human activity to influence these systems. Since changes in global energy transfer could lead to climate change, international collaborations between scientists and governments continue to produce new information and new agreements about climate change and the role we play. Issues related to climate change can also be very controversial. Such long-term and complex issues can sometimes be difficult to relate to personally.

Global warming and climate change have the potential to produce short-term and/or long-term impacts on the local and global environment. Each of these changes may potentially have an impact on your life. For example, suppose you plan to work in the agricultural industry in the future. A change in precipitation patterns could influence the type of vegetation growing in your area, which in turn could affect opportunities in your future occupation.

International agreements such as the Kyoto Protocol seek to reduce the impact of human activity on global climate, while allowing for sustainable development. Each agreement that is made may cause disagreement about the relative costs and benefits to segments of the population. For someone working in agriculture, for example, a requirement to reduce emissions by 2% in a year may require investment in more fuel-efficient machinery. This investment may not be financially possible for all people, or may not be possible on the negotiated schedule. Alternatively, the same investment could have great long-term benefit by reducing production costs. Either of these outcomes could affect your ability to find work in this area. In fact, most agreements related to climate or climate change will have political, economic, and social consequences that would impact on you, your friends, and family.

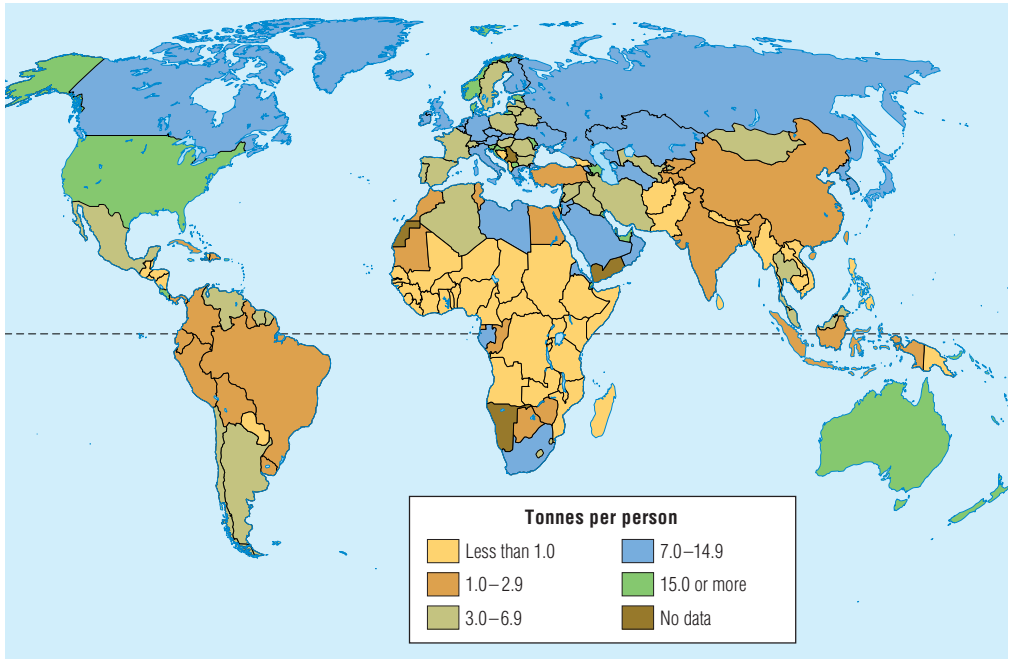
Analyze and Evaluate

1. Using your notes and additional print and electronic information, create an outline of a scenario that describes how changes in climate could potentially impact on your life 15 years from now. This scenario could include descriptions on how the changes in environment impact on your career, family, or personal time. Remember to consider the political, social, and economic factors when creating your scenario.
2. Share your ideas with one or two other classmates. Select at least one of your ideas that can be modified based on what you have learned from them.
3. Illustrate your scenario using your choice of media. This could include an illustrated story, electronic presentation, or poster.
4. After creating your scenario, make a summary of the research that supports and refutes your views. Using your notes, this textbook, and other print and electronic information sources, find examples where your views on climate change are supported. You should also find one opposing view. Your summary can be in paragraph or point form.
5. Share your scenario and research summary with the class. As you listen to other presentations, record how you might modify your work to incorporate at least one idea from someone else into your scenario.

Economics and the Kyoto Protocol

The Kyoto Protocol involves a process of signing the treaty, followed by ratification or acceptance by the voters of each country. Many developed regions, such as Canada, the United States, and the European Union, signed the treaty and agreed to the principles of the protocol. Canada ratified the Kyoto Protocol in 2002, but some other countries have yet to ratify it. The United States indicated in the spring of 2001 that they may withdraw from

FIGURE D3.18 Many nations think that agreeing to the provisions of the Kyoto Protocol would slow down their economic growth.



Source: New Scientist, 2000

FIGURE D3.19 Most greenhouse gases are emitted by the world's more developed and wealthier nations. This map shows emissions for 1998.

the Kyoto Protocol for economic reasons. China also signed the treaty but did not ratify it, and India has not signed at all. These two less developed countries are experiencing many of the changes and economic growth that more developed nations had experienced earlier in history. This economic growth is linked to increased production of greenhouse gases (Figure D3.18).

Figure D3.19 shows the greenhouse gas emissions by nation in 1998. Most of the emissions still come from the world's richer nations. Some developed nations have decided not to participate in the Kyoto Protocol until developing countries have signed the agreement. Some of these countries have stated they will not sign the Kyoto Protocol until the more developed countries reduce their greenhouse gas emissions.

*info***BIT**

Between 1988 and 1999, Syncrude Ltd has reduced the carbon dioxide emissions for the production of a barrel of oil by 26%. It is predicted that the reduction will reach 42% by 2008.

Stabilizing Greenhouse Gas Levels

Stabilizing the levels of greenhouse gases in the atmosphere depends on achieving a balance between reducing the emission of greenhouse gases and increasing the rate of their removal. For example, levels of atmospheric carbon dioxide are increased by emissions from sources such as cars and industry, and decreased when plants photosynthesize or when carbon dioxide dissolves in the oceans.

Scientists and inventors are therefore also looking for new ways of removing excess greenhouse gases from the atmosphere. One idea that some oil and gas companies are using is called **carbon dioxide sequestering**. In one version of this process, carbon dioxide gas is pumped into the ground to help extract underground oil reserves (Figure D3.20). Once the oil is removed, the gas is sealed in the empty space underground. Research is also continuing to find other methods of sequestering greenhouse gases.

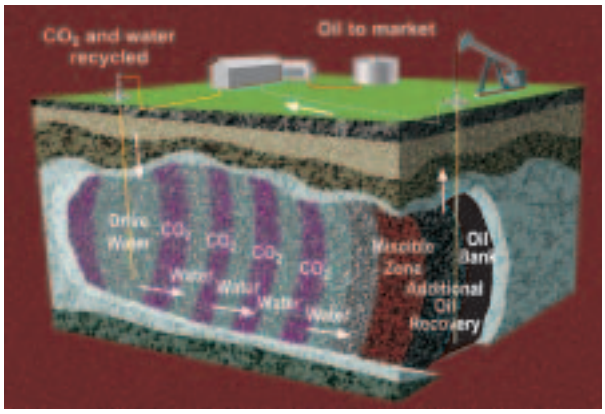


FIGURE D3.20 The Weyburn CO_2 Miscible Flood Project (shown here) will extract more oil from the pool and thus extend the life of one of Canada's oldest and largest oilfields by more than 25 years. At the same time, it will reduce emissions by using CO_2 that would otherwise be vented to the atmosphere.

*re*SEARCH

By producing their goods in ways that contribute fewer greenhouse gas emissions, many companies are finding they are also saving money. Find out what companies in your area are doing to reduce their greenhouse gas emissions, and how it affects their business. Begin your search at www.pearsoned.ca/school/science10

We can all contribute to this process in our personal choices. For example, you might choose to ride a bike, take mass transit, or walk to school to cut down on the use of a car. You could also plant trees in your neighbourhood. Many industries in Canada are also acting to reduce the amount of greenhouse gases they contribute. For example, the Canadian pulp and paper industry reduced its carbon dioxide emissions from 1990 to 1995 by 20%, by using wood waste to heat their facilities rather than fossil fuel oil. This change also had an economic benefit for the industry, since they no longer had to buy heating fuel.

D3.2 Check and Reflect

Knowledge

1. Describe the GCM climate model that scientists use to study climate change.
2. Explain why research on climate change requires international collaboration.
3. In one or two sentences, state the purpose of the Montreal Protocol.
4. What are CFCs, and what are they used for?
5. Explain why the United Nations Framework Convention on Climate Change was an important step in international action on climate change.
6. What is the Kyoto Protocol?
7. Explain what emission-reduction credits are, and give an example of how they might be used by Canada.
8. Describe two personal choices you could make to reduce your contribution to greenhouse gas emissions.
9. What is carbon dioxide sequestering?

Applications

10. If humans understood everything about the control of global climate, what other issues would still need to be considered in order for us to take action on climate change?
11. Explain why simpler computer climate models are used for some climate research.
12. Give an example of how an industry in Canada could reduce its contribution to greenhouse gas emissions.
13. Describe some of the problems in implementing the Kyoto Protocol.

Extensions

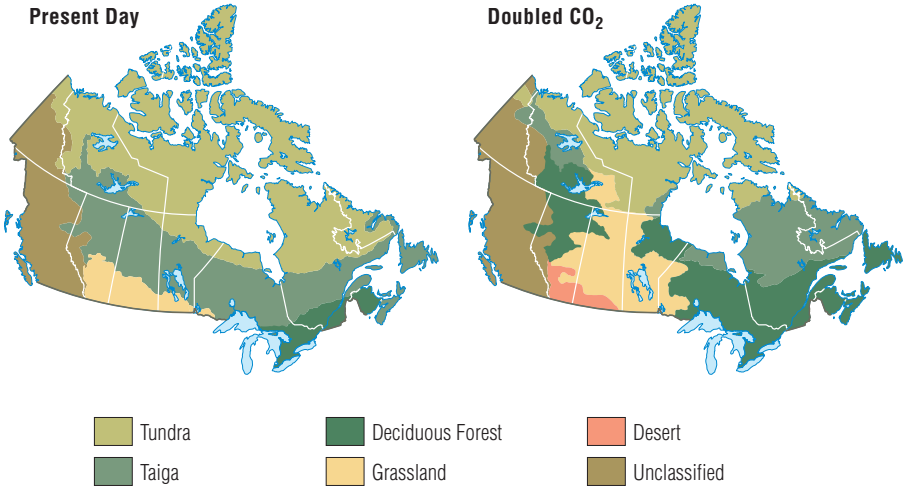
14. The IPCC assesses the work of over 2500 scientists from over 170 countries. State one benefit of having such a diverse group of people concerned about climate change.
15. Explain why all countries must act together to address social, political, and environmental issues that are related to climate change.

FIGURE D3.21 Climate change could increase the frequency and severity of forest fires in Alberta.

D 3.3 Assessing the Impacts of Climate Change

Canada is a relatively cold nation, so global warming might sometimes seem appealing. If global warming leads to climate change, however, there could be significant consequences to human life. Climate change might cause an increase in severe weather such as hurricanes, tornadoes, and thunderstorms. These could cause damage to property, crops, livestock, and even result in loss of life. Climate change could increase the number and intensity of droughts, which would cause crop failures and forest fires, damaging the agricultural, forestry (Figure D3.21), and tourism industries, and perhaps affecting the quality of our drinking water. Higher temperatures might cause more polar ice to melt, raising sea levels worldwide and flooding or eroding coastal communities. Climate change could also increase the intensity and length of heat waves.

Climate change would not just affect human life. If significant climate change occurs, then the biomes on our planet would also change. More northern regions would be impacted the most if the current warming trend in Earth's average temperature continues. The region of ice coverage would shrink, reducing the habitat of Arctic and Antarctic species. Figure D3.22 shows one prediction of changes to the vegetation of Canada that could result from climate change.



Source: Environment Canada

FIGURE D3.22 Predicted changes in Canada's forest and grassland cover as a result of a doubling of carbon dioxide levels. Note that this study used different factors to define biomes than this textbook.

As the ice receded, the albedo of Earth's polar regions would also decrease. As a result, more solar energy would be absorbed, increasing the rate at which warming of the poles occurred. Permafrost would also begin to thaw, leaving behind rotting vegetation that would increase the rate of emission of methane, a greenhouse gas, which would increase the rate of global warming even more.

Impacts of Climate Change on Alberta

The agricultural and forestry industries, and the health of Albertans, could be affected by climate change. The biomes of Alberta could also be affected, which would change the amount of suitable habitat for some species.

Droughts are predicted to become more frequent if climate change occurs. If average temperature increases, water will evaporate from soil more quickly. Without careful management, crop yields could drop by 10% to 30% as a result. To compensate, agricultural workers might have to change the crops they grow and when they plant. For example, since winter wheat can grow in dry conditions, Alberta's farmers might have to change from moisture-loving canola to this crop (Figure D3.23). Changing crops can cause an economic loss, since different crops have different worth per acre.

FIGURE D3.23 An increase in the number of droughts in Alberta would mean that some crops, like canola, could no longer be grown successfully.

Agriculture in the more northern areas of Alberta might benefit from climate change. Warmer temperatures would mean longer growing seasons and increased crop yields. Frost-sensitive crops could be grown farther north. However, insect populations are also predicted to increase with warmer temperatures, so climate change could be damaging to agriculture overall.

Forests could also be affected by climate change. Drier conditions would slow the growth of forests and increase the risk of forest fires. As with crop plants, the retreat of ice cover could allow trees to grow farther north than they do now. However, warmer temperatures could also increase the population of insects that can harm forests, such as spruce budworm (Figure D3.24). These consequences of climate change could harm both the forestry industry and the wildlife that depend on forests for their habitat.

If climate change occurs too rapidly, natural ecosystems, protected areas, and wildlife in Alberta would have to adapt quickly to new climate conditions. Some species would not survive. For example, plant species that could not survive the new climate conditions would die out and other species would move in. This would shift the boundaries of Alberta's biomes. Shrinking of the tundra and taiga biomes would mean far less habitat for the organisms that live in these biomes. Animals that depend on wetlands, such as the trumpeter swan, would also be at higher risk of extinction.

Warmer temperatures could also affect the health of Albertans. If climate change caused longer and more intense heat waves, air pollution in larger urban areas would worsen. People with respiratory diseases, such as asthma, would suffer more illness. Diseases associated with insects in warmer areas would also increase in Alberta. For example, Lyme disease is spread by a species of ticks that cannot survive cold temperatures. This tick could survive in Alberta if the average temperature continues to increase, and Albertans would be at risk of this disease for the first time.

FIGURE D3.24 Warmer temperatures are linked with increases in insect populations, many of which are harmful to the agricultural and forestry industries.

Activity D20

Decision-Making Investigation

Student Reference 11

Required Skills
- Initiating and Planning
- Performing and Recording
- Analyzing and Interpreting
- Communication and Teamwork

The Impact of Climate Change on a Taiga Biome

Begin your search at
www.pearsoned.ca/school/science10

FIGURE D3.25 Many species that live in polar regions would be threatened by climate change.

The Issue

How will climate change affect tourism?

Background Information

The polar bear is a well-loved symbol of northern Canada (Figure D3.25). The Canadian Wildlife Service has been gathering data on the polar bears in Churchill, Manitoba, for over 30 years, and using this information to determine how changes in the environment due to climate change are affecting the bears. Polar bears eat only during the winter, when they are on the ice. They depend on large areas of ice cover to be able to travel the great distances needed to hunt successfully. Once temperatures increase and the ice breaks up, the bears' abilities to catch prey become very limited. Monitoring when the ice breaks is therefore an important tool in predicting the bears' chances of long-term survival.

According to Environment Canada, the average temperature in western Hudson Bay has been increasing by 0.3°C to 0.4°C every decade since 1950. As a result, the ice is breaking up 2 to 4 weeks earlier than 20 years ago, forcing bears to come ashore hungrier and leaner. The bears then do not eat until the ice freezes up again, and the warmer temperatures are also causing the ice to form later than in the past. Many female polar bears are unable to hunt long enough to gain sufficient fat to sustain themselves and their cubs over the winter. Scientists at Environment Canada have studied adult male and female bears over the same 20-year period that declines in ice cover were observed. They have concluded that there is a direct correlation between early ice break-up and a decline in the health of the polar bears, in the number of cubs in a litter, and in the survival rate of the cubs. The bears are also forced to look for food in areas close to humans, such as in garbage dumps, sometimes with tragic results.

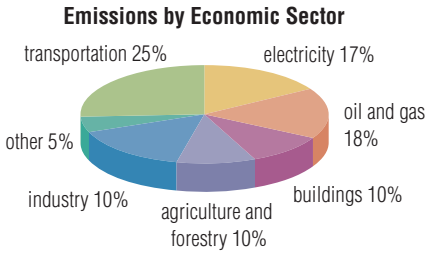
From climate models, scientists predict that western and southern Hudson Bay could become 3°C to 5°C warmer within 50 years. Because the polar bears of this region are at the southernmost point of their range, they serve as a warning of the potential consequences of climate change to many other species. Some scientists predict the polar bear will be extinct in 50 to 100 years. For a town like Churchill, where polar bear tourism accounts for 60% of the economy, this could also mean economic and social disaster.

Analyze and Evaluate

1. Restate the issue concerning the problem of polar bears and climate change in Churchill, Manitoba.
2. List the short-term and long-term consequences related to this issue.
3. In 1991, Mount Pinatubo, a volcano in the Philippines, erupted. The gases that were released into the atmosphere cooled the planet. Use electronic and print resources to research the effect this cooling had on the polar bear habitat in the Hudson Bay area, and on the polar bear population size in that area.
4. Imagine you are a community member in the town of Churchill. Concerns have been raised about the increased number of sightings of polar bears in town. Prepare a position paper to present at a town council meeting from one of the following points of view. Remember to identify the benefits and risks associated with this issue from that point of view.
   - mayor
   - meteorologist
   - local hotel owner
   - local tourist operator
   - local parent
   - climate change scientist

Canada's Action Plan on Climate Change

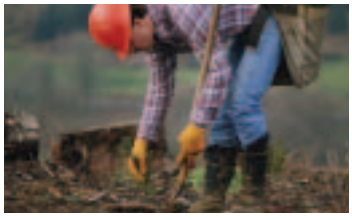
Figure D3.26 shows the contribution made by different sectors of Canadian society to greenhouse gas emissions in 1998. The Government of Canada has developed an action plan to reduce greenhouse gas emissions in those sectors that impact greenhouse gas emissions the most (Table D3.3).



Source: Environment Canada

FIGURE D3.26 Contribution of economic sectors in Canada to total greenhouse gas emissions in 1998

TABLE D3.3 Key Features of *The Government of Canada's Action Plan 2000 on Climate Change*

Sector	Actions to Reduce Greenhouse Gas Emissions
Transportation 	• develop more fuel-efficient vehicles • increase use of fuels that produce less carbon dioxide, such as ethanol • develop technologies to reduce or eliminate emissions, such as hydrogen-powered fuel cells • encourage efficiencies in the transport of freight • encourage more use of public transit
Energy 	• find and create suitable carbon dioxide capture and storage sites • work with oil and gas sector to improve energy efficiency • support the development of emerging renewable energy sources that do not emit greenhouse gases, such as solar and wind energies • educate Canadian citizens on how they can act to reduce the greenhouse gas emissions contributed by their personal actions
Buildings 	• encourage businesses to make renovations that use more energy-efficient heating and cooling systems • promote construction of energy-efficient residential housing • improve energy-efficiency standards for household appliances
Agriculture and Forestry 	• promote best practices in fertilizer application, and in soil and livestock management • promote the planting of trees in areas where no trees previously existed
Industry 	• conduct energy-efficiency audits to identify further areas for improvement • support the use of renewable energy technologies, such as biomass, solar energy, and geothermal energy for heating

reSEARCH

Select one area of life in Alberta that could be impacted by climate change. Look for additional information, then analyze the risks and benefits of climate change on the area you chose. Begin your search at

www.pearsoned.ca/school/science10

Balancing Environmental, Social, and Economic Goals

Although the Government of Canada has ratified the Kyoto Protocol, some Canadians think this agreement is not the best way to proceed. Some believe it will be impossible for Canada to meet the objectives of the Kyoto Protocol unless major changes are implemented soon, despite some economic costs. Others are concerned that the economic impacts of the Kyoto Protocol will be too severe, and so will not allow sustainable development of Canada's resources. In 2002, the Government of Alberta produced its own action plan against human impact on climate, called *Albertans & Climate Change*. This plan offered alternative ways to reduce greenhouse gas emissions other than those that would be required by the Kyoto Protocol.

However Canadians proceed, we will all need to be involved in decisions related to climate change. For example, oil, gas, and electricity production account for 35% of Canada's greenhouse gases. If a reduction is to be made, everyone must reduce their energy use. No one group of people, political party, or company can do it alone. It will require an effort by everyone to change their present usage of energy if emissions of greenhouse gases are to be reduced.

D3.3 Check and Reflect

Knowledge

1. Describe at least three consequences of climate change to Canada.
2. Why would tundra biomes be impacted more by climate change than other biomes?
3. Explain why climate change could change the boundaries of the planet's biomes.
4. Outline the potential consequences of climate change on the agriculture industry in Alberta.
5. Describe the potential consequences of warmer temperatures on the forests of Alberta.
6. State the sectors that the government of Canada has targeted as its focus for reduction of greenhouse gas emissions.
7. List five ways that the transportation sector could reduce greenhouse gas emissions.
8. State which sector of Canadian society could benefit from climate change, and describe the potential impacts.

Applications

9. Illustrate the data in the pie chart in Figure D3.26 in another graphical format.
10. Describe some of the changes that can be made in the day-to-day business of Canada to help us to reduce greenhouse gas emissions.
11. Different computer climate models generate different conclusions on the potential for drought in Alberta as a result of climate change. Suggest possible reasons for these conflicting conclusions.
12. Using an example, describe how climate change could impact the tourism industry.

Extensions

13. Use print and electronic resources to find the current status of Canada with respect to the Kyoto Protocol. Summarize your findings in one or two paragraphs.
14. Select one of the five sectors identified in Table D3.3 that have been targeted by the Canadian government as areas that could significantly reduce their greenhouse gas emissions. Carry out additional research to find out what has changed in this sector to address the problem of greenhouse gas emissions.
15. Use print and electronic resources to research any new predictions on the impacts of climate change on Alberta.

Section Review

Knowledge

1. Describe the role of the IPCC.
2. Identify at least three human activities that add greenhouse gases to the atmosphere.
3. Describe how the concentrations of greenhouse gases on Earth are changing, according to the evidence collected by scientists.
4. According to IPCC data, what was the increase in Earth's average surface temperature during the 20th century?
5. Describe the position of the IPCC on the relationship between the increase in average surface temperature on Earth, and climate change.
6. Describe two pieces of evidence that do not support the theory that Earth is currently undergoing climate change.
7. What is global warming?
8. Carbon dioxide concentrations in the atmosphere are currently rising. Explain why this is occurring by referring to carbon sinks and carbon sources.
9. Give one example of how carbon dioxide gas is removed from the atmosphere.
10. How is the enhanced greenhouse effect thought to be connected to global warming?
11. What did the nations that signed the Montreal Protocol agree to do?
12. Describe the impact of CFCs on the environment.
13. Describe the key idea that emerged from the United Nations Framework Convention on Climate Change.
14. Describe the commitment that Canada would need to meet, according to the provisions of the Kyoto Protocol.
15. List the five areas that have been identified by the Government of Canada as targets for greenhouse gas emission reduction.
16. Explain how using renewable energy sources could help to reduce greenhouse gas emissions.
17. Describe how life in Alberta could be impacted by climate change.
18. Outline how Alberta's forests would be impacted by climate change. Include examples of social, environmental, and economic impacts.

Applications

19. In a short paragraph, describe some of the possible impacts of the enhanced greenhouse effect on the world's climate.
20. Explain why it is important to know the level of confidence that scientists give to their climate change predictions.
21. Why is sustainable development a global issue?
22. State the key international agreements dealing with issues of global climate change. Describe the goals and results of these agreements.
23. Describe the three ways that a country can earn emission-reduction credits under the Kyoto Protocol.
24. Describe how buildings contribute to greenhouse gases. Suggest some ways that the emissions of greenhouse gases from buildings can be reduced.
25. Describe how human health could be affected by climate change.

Extensions

26. Explain why the following statement is true: *The study of climate change is not a precise science.*
27. Climate change may occur so slowly that it would have little or no effect during your lifetime. If this were the case, do you think that governments, scientists, and other citizens would no longer need to be concerned about climate change? Defend your position.
28. Create a concept map of the key terms used in this section.

Risky Solutions

Background Information

Since climate change could have global consequences, some people have suggested some very innovative technologies to reduce or reverse the impact of human activity on Earth's climate. However, every new technology has the potential to create new problems, so both the positive and negative potentials must be considered in the final decision of whether or not to adopt a new technology.

Scenario

You are part of a committee that allocates research funds for studying new technologies to minimize or reverse the effects of human activity on climate. Funds are limited, so your committee can only give financial support to one project. The proposed projects are summarized below.

A) Iron Fertilization

This project would reduce carbon dioxide levels by increasing the oceans' populations of algae, which use carbon dioxide during photosynthesis. Algae growth would be stimulated by adding iron to their environment. Supertankers would travel the world, releasing millions of tonnes of iron on the oceans' surfaces.

B) Sulfuric Acid Screen

In the atmosphere, sulfur dioxide gas combines with water vapour and forms drops of sulfuric acid, which reflect sunlight back into space. In this project, large airplanes would fly throughout Earth's atmosphere each year, releasing tonnes of sulfur dioxide gas. This would produce a sulfuric acid screen, which would decrease the insolation of Earth's surface, and so decrease the average global temperature.

C) Reflecting Balloons

The authors of this proposal would release billions of large balloons into the atmosphere. These balloons would reflect some of the incoming solar energy, reducing the insolation of Earth's surface. This could change Earth's net radiation budget back to its value prior to the Industrial Revolution.

D) Burning Sulfur

This group proposes to send ships that are burning tonnes of sulfur travelling over the world's oceans. The burning sulfur would release large amounts of sulfur particles into the atmosphere, and increase the rate of cloud formation. The resulting increase in cloud cover would reduce the amount of sunlight reaching Earth's surface.

E) Sequestering Carbon Dioxide in the Ocean

Levels of carbon dioxide in Earth's atmosphere are increasing, contributing significantly to the enhanced greenhouse effect. This group proposes to remove carbon dioxide from the atmosphere and inject it directly into the deep ocean. The carbon dioxide gas would then dissolve in the water, removing it from the atmosphere and storing it in the ocean.

Research the Issue

Research the issue by referring to the following resources:

1. Look at the Web. Check the Internet for information regarding the particular technology you chose.
2. Ask the experts. Contact climate research institutes, companies involved in making or testing the technology, and environmental groups.
3. Look in magazines, newspapers, or books for information regarding the technology you chose.

Analyze the Issue

4. Summarize the information you have found in a short report or electronic presentation. Include your recommendation to the committee on whether they should support further research into this particular idea. Your report or presentation should include current information on the technology, and discuss the advantages and disadvantages of the idea.

Address the Issue

5. Present your findings to your classmates in a convincing presentation.

A Personal Plan for Reducing Carbon Dioxide Emissions

Currently, Canada contributes an average of 17 000 kg per person of carbon dioxide gas to the atmosphere every year. If each of us could reduce our emissions by only 2% a year, this amount would drop to about 15 000 kg per person in only 10 years! In this activity, you will create a personal plan to reduce the greenhouse gas emissions of you and your family.

Potential Reduction per Action

Action	Estimated CO_2 Reduction*
Wash clothes in warm or cold water	160 kg CO_2/y
Lower room temperature	140 kg CO_2/y per 1°C reduction
Use compact fluorescent bulbs	230 kg CO_2/y per 6 bulbs replaced
Reduce use of vehicle	48 kg CO_2/L of gasoline saved
Buy a more energy-efficient air conditioner	270 kg CO_2/y
Walk, bike, carpool, or use mass transit	3.32 kg CO_2/L of gasoline saved
Plant a tree near your house	6.0 kg CO_2/y per tree
Do not use heat to dry dishes in the dishwasher	45 kg CO_2/y
Lower water-heater thermostat from 60°C to 49°C	90 kg CO_2/y
Wrap water heater in thermal blanket	110 kg CO_2/y
Install low-flow shower heads	160 kg CO_2/y
Caulk and weather-strip doors and windows	290 kg CO_2/y
Insulate the attic	910 kg CO_2/y
Lower waste production by reducing, recycling, and reusing	540 kg CO_2/y per 10% reduction
Maintain furnaces and air conditioners, and clean or replace air filters	160 kg CO_2/y
Install energy-efficient windows	460 kg CO_2/y

*Values are an average figure and will not represent specific locations or situations.

Source: Environmental Defence

Criteria for Success

- Your plan must reduce your family's carbon dioxide emissions by 2% over one year, assuming that your current emissions are at the Canadian average of 17 000 kg per person per year.
- Your plan must indicate the reduction in carbon dioxide emissions you will achieve for each month of the year.
- Your plan must take into account the economic and social costs to your family, and balance them with the benefits of your plan.

Procedure

1. Identify actions, on the table provided, that you think are most likely to be possible for your family. Determine the reduction of carbon dioxide emissions that would be achieved for each action for each month and for one year.
2. Determine if the emission reductions from your plan will meet the 2% goal. Modify your plan to meet this goal if necessary.
3. Research the economic costs of implementing your plan. For example, if your plan includes replacing the bulbs in your home with compact fluorescent bulbs, find out the cost of this replacement. With your family, determine how able you are to meet these costs.
4. Consider the social costs of implementing your plan. For example, you might find out how willing your family is to forgo entertainment in order to pay for replacement light bulbs.

Analysis

1. Review the environmental, social, and economic costs of the actions on your plan. Do you need to modify your plan based on these considerations?

Reporting

2. Draw graphs or charts to illustrate the monthly carbon dioxide reductions that will be achieved by your family through your plan. Include a one-page summary of your plan, with a place for the signature of everyone who will be involved in carrying out the plan.

UNIT D

Unit Summary

D 1.0 Climate results from interactions among the components of the biosphere.

Key Concepts:

- social and environmental contexts for investigating climate change

Learnings

- Climate is the average weather conditions that occur in a region. Climate change is change that occurs in the climate of a region over time, usually a minimum of 30 years.
- The components of the biosphere are the lithosphere, hydrosphere, and atmosphere.

D 2.0 Global systems transfer energy through the biosphere.

Key Concepts:

- solar radiation budget
- climate zones, transfer of thermal energy by the hydrosphere and the atmosphere
- hydrologic cycle and phase change
- relationship between biomes and solar energy and climate

Learnings

- Thermal energy is the energy possessed by a substance by virtue of the kinetic energy of its molecules or atoms.
- Insolation is the amount of solar energy received by a region of Earth's surface. Insolation varies with latitude, albedo, cloud cover, and atmospheric dust.
- The net radiation budget is the difference between the amount of incoming radiation and outgoing radiation from Earth's surface and atmosphere.
- Thermal energy transfer is the movement of thermal energy from an area of high temperature to an area of low temperature.
- Global winds result from convection in the atmosphere, and are modified by the Coriolis effect, which is the deflection of any object from a straight-line path by Earth's rotation.
- Ocean currents modify the climate of coastal regions due to the high specific heat capacity of water. The specific heat capacity (c) of a substance is the amount of energy required to raise the temperature of 1 g of the substance by 1°C.
- The quantity of thermal energy, Q, is the amount of thermal energy required to change the temperature of a specific mass, m, of the substance by a certain number of degrees, Δt.
- The hydrologic cycle releases and absorbs thermal energy during phase changes. The heat of fusion, H_{fus}, of a substance is the amount of energy required to change 1 mol of the substance from solid phase to liquid phase, without a change in temperature. The heat of vaporization of a substance, H_{vap}, is the amount of energy required to change 1 mol of the substance from liquid phase to vapour phase, without a change in temperature.
- A biome is a large geographical region with a particular range of temperature and precipitation levels, and the plants and animals that are adapted to those climate conditions. Biomes are open systems.
- A climatograph is a summary of the average temperature and precipitation for each month of the year for a given location, presented as a graph.

D 3.0 Changes in global energy transfer could cause climate change, and impact human life and the biosphere.

Key Concepts:

- social and environmental contexts for investigating climate change
- human activity and climate change

Learnings

- The enhanced greenhouse effect is the change in Earth's net radiation budget caused by the increase in human-generated greenhouse gases.
- Climate change is a global issue that requires international collaboration.
- The effects of climate change are difficult to predict.

UNIT D

Unit Review

Vocabulary

1. Create a concept map with the term "climate change" at the centre, that links all the terms in the list below.

albedo
angle of incidence
angle of inclination
atmosphere
biome
climate
climate zone
convection
energy
enhanced greenhouse effect
fossil fuels
global warming
greenhouse gases
hydrologic cycle
hydrosphere
lithosphere
natural greenhouse effect
net radiation budget
ozone layer
solar energy
specific heat capacity
sustainable development
thermal energy
thermal energy transfer
weather

Knowledge

D 1.0

2. Explain the difference between weather and climate.
3. Give an example of climate and an example of weather that illustrates the difference between these concepts.
4. Compare the composition of Earth's atmosphere to the atmospheres of Mars and Venus.
5. List the four layers of Earth's atmosphere.
6. Explain how temperature varies with altitude in Earth's atmosphere.
7. What is the ozone layer?
8. Draw a diagram to illustrate the components of the lithosphere.
9. In point form, outline the characteristics of the hydrosphere.
10. Describe two examples of the effect of climate on your daily life.
11. In a short paragraph, describe the effect of climate on the behaviour of one animal species.
12. What types of evidence are used to provide evidence of climate change?

D 2.0

13. In a sentence, identify the main source of Earth's energy.
14. Identify four different types of radiation that can be found in solar radiation.
15. What is radiant energy?
16. Define insolation.
17. Describe the relationship between Earth's angle of inclination and the seasons.
18. State the angle of inclination of Earth.
19. Relate the effect of reflection and absorption in the atmosphere to the amount of solar energy that reaches Earth's surface.
20. A small proportion of the solar energy that reaches Earth is used for a process not related to Earth's climate. Identify this other process.
21. Describe how insolation varies with latitude.
22. Compare the relative albedo of Earth's surface in an area covered with water, such as the ocean, and an area covered by grasslands.
23. Explain why a city at the equator would receive more solar energy on average than would Red Deer, Alberta.
24. State the component of the atmosphere that is the main contributor to the natural greenhouse effect.
25. Identify three greenhouse gases.
26. Explain the relationship of the net radiation budget to Earth's climate.
27. What area of Earth has a net radiation budget surplus?

Unit Review

28. Is convection or conduction more important in moving thermal energy in the atmosphere?

29. Identify what is transferred by global winds.

30. Describe the difference in the Coriolis effect in the Northern Hemisphere and the Southern Hemisphere.

31. Distinguish between the Coriolis effect and the jet stream.

32. Describe how convection of the gases in the atmosphere causes differences in air pressure.

33. Describe how differences in the insolation of Earth's surface are related to wind.

34. Identify the variables that must be controlled in order to determine the specific heat capacity of a substance.

35. What is the function of a calorimeter?

36. Describe how thermal energy is transferred in the hydrologic cycle.

37. In one or two sentences, distinguish between the heat of fusion and the heat of vaporization of a substance.

38. Describe how phase changes of water transfer thermal energy.

39. Distinguish between the biosphere and a biome.

40. Name at least three biomes that are found in Canada, and state one characteristic of each.

41. Describe how most energy enters a biome.

42. Give an example of a way in which matter might move in and out of a biome.

43. Identify the biomes in western Canada.

44. In one or two sentences, explain the purpose of a climatograph.

45. Describe the information that is found on a climatograph.

46. Explain how climatographs can be used to analyze thermal energy transfer in biomes.

D 3.0

47. Identify the components of the biosphere that are considered in general circulation models of climate.

48. State the name of the international organization that reports scientific information on climate change to the public.

49. Distinguish between the natural greenhouse effect and global warming.

50. Explain why greenhouse gases like methane and nitrous oxide are thought to have more effect on Earth's climate today than does water vapour.

51. Identify the human activity that contributes the highest level of greenhouse gas emissions to the atmosphere.

52. What is the enhanced greenhouse effect?

53. Explain why carbon sinks are important to the enhanced greenhouse effect.

54. Describe two pieces of evidence that support the view that climate change is occurring.

55. Explain why climatologists include the confidence level of their data and predictions when reporting the results of their investigations.

56. Create a timeline of the international agreements that address the issue of climate change.

57. In your own words, describe the main points of the Montreal Protocol.

58. Describe the emission-reduction credits of the Kyoto Protocol.

59. Describe the purpose of the work published in the government document entitled *Canada Country Study: Climate Impacts and Adaptations.*

60. Describe three potential consequences of climate change that would affect Canada.

61. In a paragraph, predict how the increase in average global temperature could affect the albedo of the Arctic in the future.

62. Outline the main points of *The Government of Canada's Action Plan on Climate Change.*

Unit Review

63. Describe a change you could make in your daily life that would help to reduce the emission of greenhouse gases.

Applications

64. Rewrite the following statements to correct any errors:
   a) The last two weeks of rain have made the climate miserable.
   b) This kind of weather is the reason that good crops grow here every year.

65. Relate a personal experience in which you had to modify your environment because of the weather.

66. Relate a personal experience in which you had to modify your environment because of the climate.

67. Give two examples of anecdotal evidence of climate change and two examples of scientific evidence.

68. Create a concept map using the terms: biosphere, atmosphere, lithosphere, and hydrosphere.

69. Describe one distinguishing characteristic of each layer of Earth's atmosphere.

70. Describe the effect on Earth's climate of the release of large amounts of atmospheric dust into the atmosphere.

71. Describe an example of how the components of the biosphere can interact to moderate the climate conditions of an area.

72. Why is it useful for scientists to divide the Earth into different biomes?

73. If the borders of a biome were to change, how would it affect the organisms in the area? Would it affect humans? Give examples to illustrate your answer.

74. Explain the difference between a system and its surroundings.

75. Using an example, distinguish between a closed system and an open system.

76. Compare and contrast the features that classify cells and biomes as open systems.

77. Suggest one possible change that a biome might experience if the input of solar energy into the biome were reduced.

78. Outline the relationship between variations in insolation, and the types of plants and animals in a biome.

79. How does the angle of inclination and the angle of incidence affect the insolation of your community?

80. Does Canada have a higher average albedo in summer or in winter? Why?

81. Describe the natural greenhouse effect.

82. Explain how convection moves thermal energy from one area of a fluid to another. Include a description of any changes in density that occur.

83. Describe how thermal energy is transferred from one area to another on Earth.

84. Draw a diagram to illustrate the variation of net radiation budget with latitude.

85. Calculate the quantity of thermal energy required to increase the temperature of 100.0 kg of water from 10.0°C to 20.0°C. The specific heat capacity of water is 4.19 J/g·°C.

86. Calculate the temperature change that occurs when 1290 J of thermal energy are added to 12.0 g of water and no phase change occurs. The specific heat capacity of water is 4.19 J/g·°C.

87. The temperature of a piece of iron increases from 24.0°C to 46.0°C when 148.5 J of thermal energy are applied. Given that the specific heat capacity of iron is 0.449 J/g·°C, determine the mass of the iron.

88. When 10.0 J of thermal energy are added to a 15.0-g mass of gold, the temperature of the gold increases by 5.1°C. What is the experimental specific heat capacity of gold?

Unit Review

89. Calculate the amount of thermal energy required to melt 200 g of ice at 0.0°C. The molar mass of ice is 18.02 g/mol, and the heat of fusion of ice is 6.01 kJ/mol.

90. Determine the amount of thermal energy required to evaporate 2.00 mol of liquid water at 100.0°C. The heat of vaporization of water is 40.65 kJ/mol.

91. Calculate the number of moles of liquid water at 100.0°C that can be evaporated by the addition of 203 kJ of thermal energy. The heat of vaporization of water is 40.65 kJ/mol.

92. If 21 kJ of thermal energy are added to ice at 0.0°C, how many grams will change to the liquid phase? The molar mass of ice is 18.02 g/mol, and the heat of fusion of ice is 6.01 kJ/mol.

93. State the change in the levels of greenhouse gases in the atmosphere that occurred in the 20th century.

94. Agree or disagree with the following statement: *Investigating climate change is a responsibility of all the countries on Earth.* Justify your answer.

95. Describe at least two economic or social factors that have influenced the implementation of the Kyoto Protocol.

96. List at least five effects that climate change would have on Alberta. Arrange your list from the largest to the smallest effect, and explain how you decided the order.

Extensions

97. Explain why some people argue that there is currently insufficient evidence to conclude that climate change is occurring or is likely to occur.

98. Imagine that farmers in an area near to your community are reporting that the growing season is longer than in the past. Write a hypothesis to explain this observation. Describe how you might use weather records to test your hypothesis.

99. Explain why a biome is considered to be an open system, using the terms: input, output, energy, and matter.

100. The atmosphere above some areas of Earth's surface is undergoing ozone depletion. The levels of what types of radiation would likely increase at Earth's surface in these areas as a result?

101. Describe the potential consequences to climate if a volcano were to erupt and release large amounts of dust into the atmosphere.

102. If a mass of cold air is approaching your town from the west during the summer, predict the direction in which the wind will be blowing.

103. Suggest one difference in Earth's climate that would result if water had a low specific heat capacity.

104. Why is the assessment of the IPCC on climate change taken more seriously than the assessment of any one individual scientist?

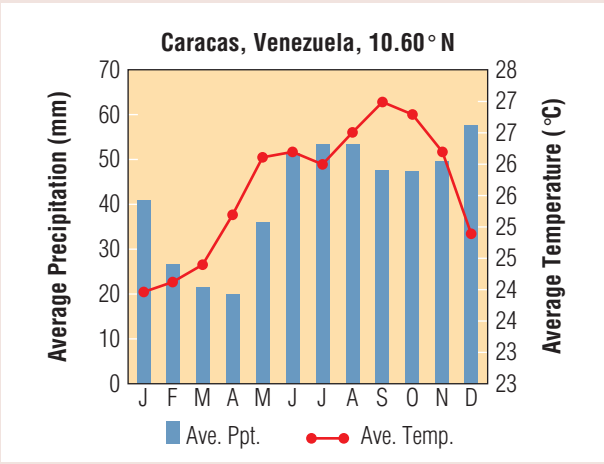
105. Suggest some advantages and disadvantages to climatologists reporting a confidence estimate of the data or predictions in their work.

106. Explain the following statement: *Climate change is a social, political, and environmental issue.*

Skills Practice

107. From the information presented in the climatograph on the next page, write a travel brochure that provides visitors to Caracas with information such as the best time to visit, the type of clothing they should bring, and what kind of accommodation would be appropriate for a comfortable stay in this climate.

Unit Review



Source: World Climate (www.worldclimate.com)

108. The cities of Fort McMurray, Alberta, and Inverewe, Scotland, are located at similar latitudes. Construct a climatograph for both cities, using the given data. Write a paragraph describing the climates of the cities, and propose a reason for any differences.

Average Climate Conditions of Fort McMurray, Alberta, Canada, 56.4° N

Month	Average Temperature (°C)	Average Precipitation (mm)
Jan	−19.9	20.4
Feb	−14.9	16.0
Mar	−7.9	17.3
Apr	2.8	22.6
May	10.1	40.7
June	14.6	63.9
July	16.6	79.1
Aug	15.2	71.8
Sept	9.1	51.4
Oct	3.3	32.2
Nov	−9.0	26.4
Dec	−17.3	23.0

Source: Environment Canada

Average Climate Conditions of Inverewe, Scotland United Kingdom, 57.8° N

Month	Average Temperature (°C)	Average Precipitation (mm)
Jan	4.5	205.5
Feb	4.6	124.5
Mar	6.3	130.3
Apr	6.2	69.2
May	10.4	58.4
June	12.0	79.1
July	13.7	60.7
Aug	14.1	124.8
Sept	12.7	208.9
Oct	8.9	265.8
Nov	5.6	163.6
Dec	4.2	224.9

Source: Met Office, United Kingdom

Self Assessment

109. What is one thing you learned in this unit that you would like to find out more about?

110. Why is it important to consider alternative perspectives with any issue on global climate change?

111. Describe one aspect of your lifestyle you could modify or change to help reduce human impact on climate change.

112. Identify at least one personal, one social, and one environmental consequence of the change to your lifestyle that you suggested in your answer to question 111 above.